Effekter og økonomiske konsekvenser ved afsaltet havvand til drikkevandsformål

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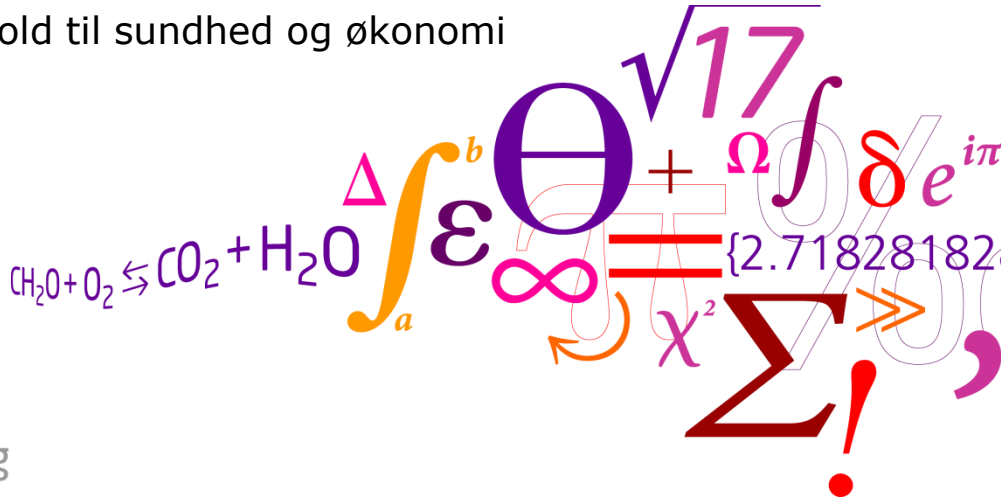
Martin Rygaard

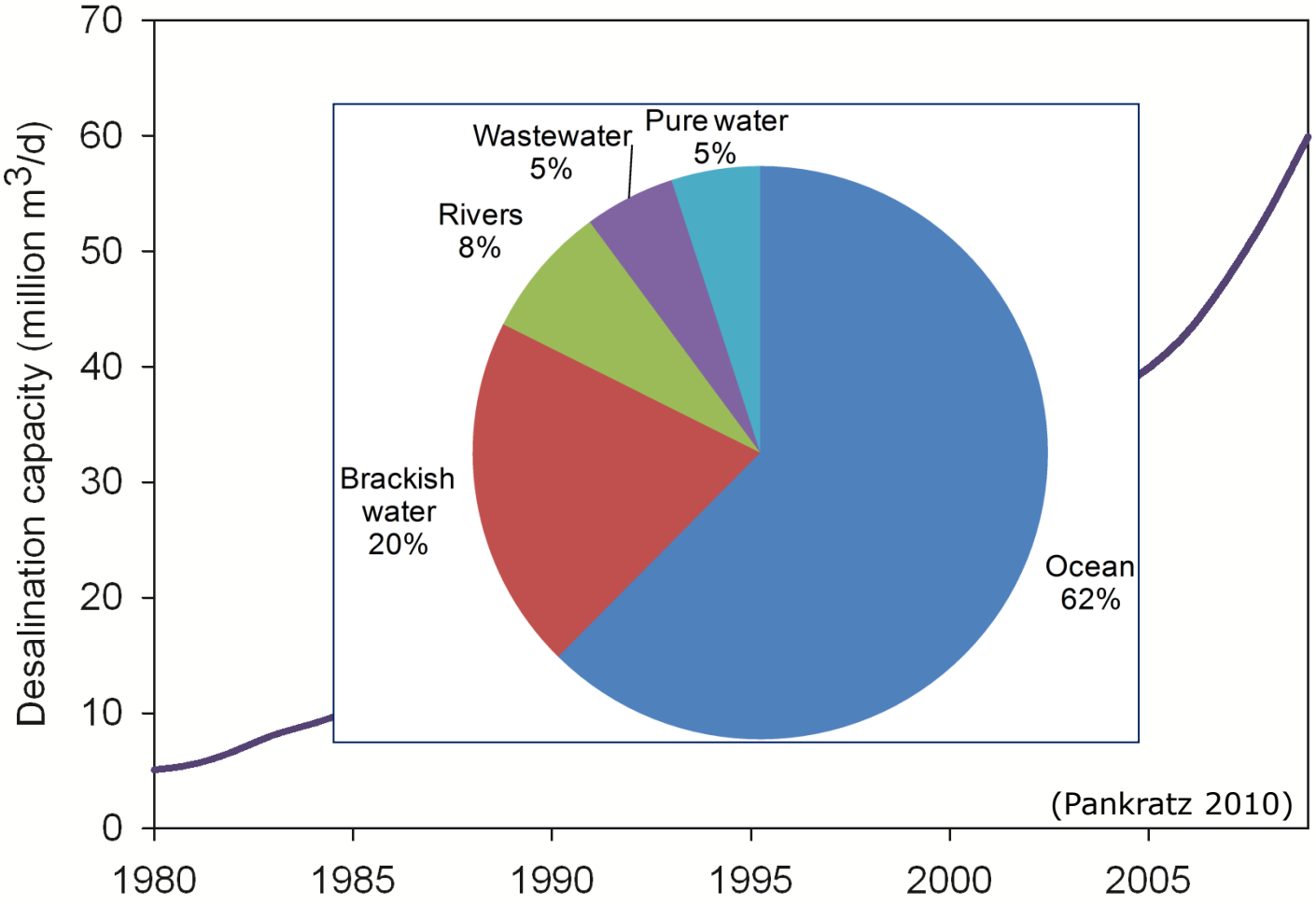
Med bidrag fra Erik Arvin, Hans-Jørgen Albrechtsen & Philip J. Binning

2015/04/14 ATV Jord og Grundvand:
Kvaliteten af grund – og drikkevand i forhold til sundhed og økonomi



DTU Environment
Department of Environmental Engineering

Udviklingen i afsaltning



Economy

Health/ nutrition

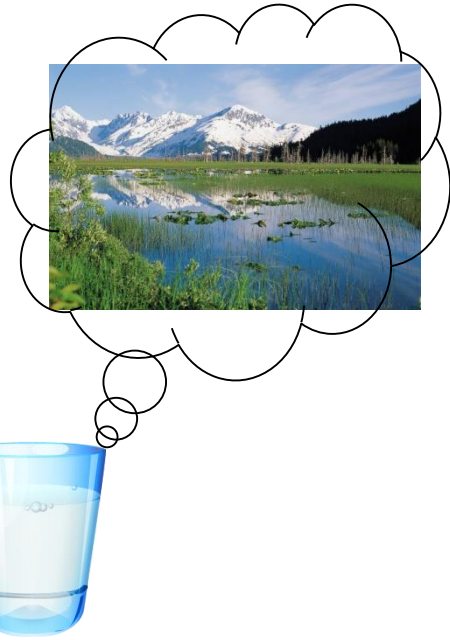
Corrosion

IWA Bonn charter:
Good safe drinking water that has the trust of consumers

Resources/ Environment

Aesthetics/ accept

Applicability



Formål

1. Hvilke effekter kan tilskrives en ændret drikkevandskvalitet?
2. Hvordan opgøres effekterne og kan en kvantificering af effekterne bruges til at definere en optimal vandkvalitet?
3. Hvordan håndteres usikkerheder?

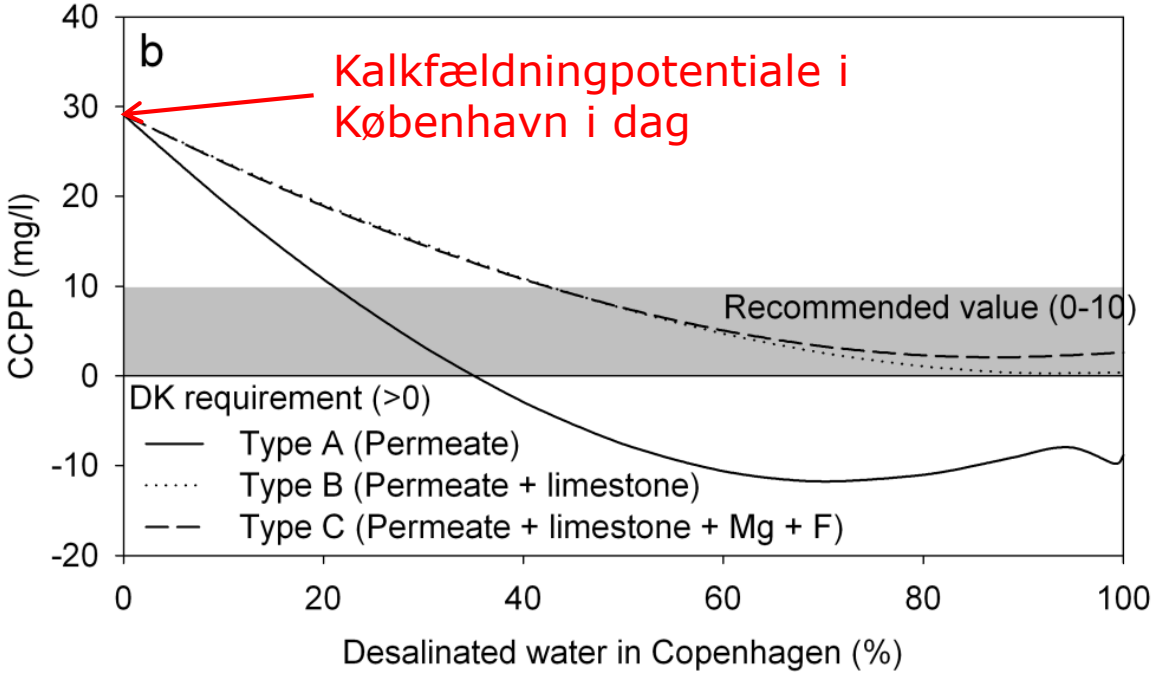
Effekterne er opgjort for 2 casestudier i København og Perth, Australien

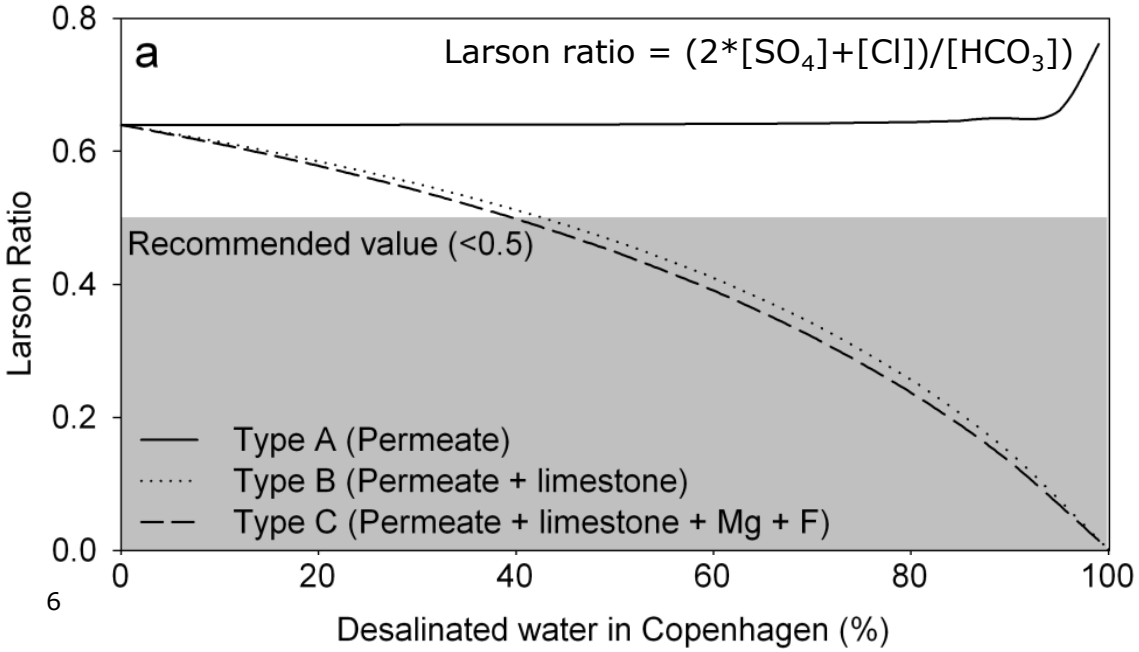
Estimate possible water composition

At blande vand 1

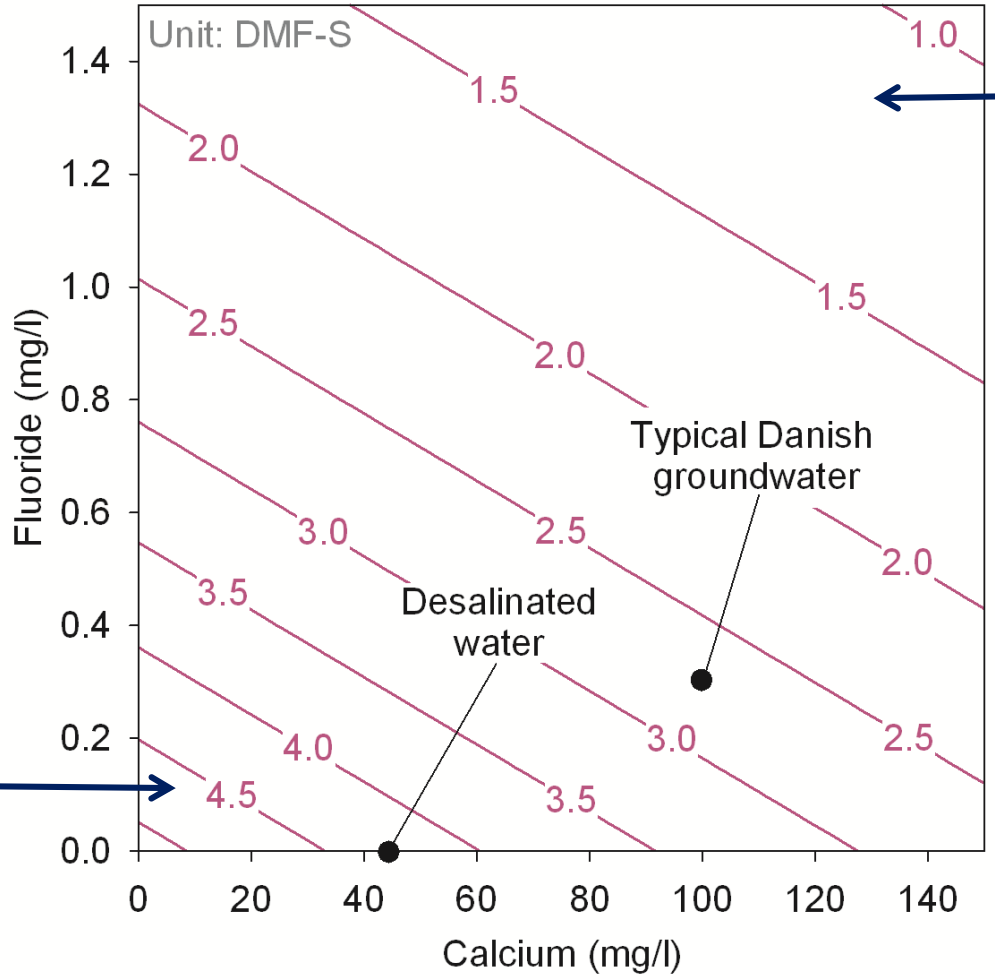
	Danske krav	Typisk Grundvand	Afsaltning Type A	Afsaltning Type B	Afsaltning Type C
Behandlingstrin		Aeration Sand filtration	Ultrafiltration Reverse osmosis CO_2 stripping	Ultrafiltration Reverse osmosis Acidified with CO_2 Dissolution of limestone CO_2 stripping	Ultrafiltration Reverse osmosis Acidified with CO_2 Dissolution of limestone CO_2 stripping Ion-exchange Fluoridation
pH	7 – 8.5	7.5	5.2	7.9	8.4
Alk	>82 (>100 mg HCO_3)	286	-0.3	108	122
Hardness (as CaCO3)	89 - 534 (5-30° dH)	369	0.	108	124
Ca	<200	117	0	43	19
Mg	<50	19	0	0	19
F	<1.5	0.48	0	0	0.75
SO_4	<250	83	0	0	0
Cl	<250	69	0.1	0.1	0.1
TDS	<1500	503	0	108	112
Larson ratio	-	0.6	N/A	0.0	0.0
CCPP	>0	29	-8.8	0.4	2.6

At blande vand 2





Sundhedseffekter eksempel 1



Mindre karies

Mere caries

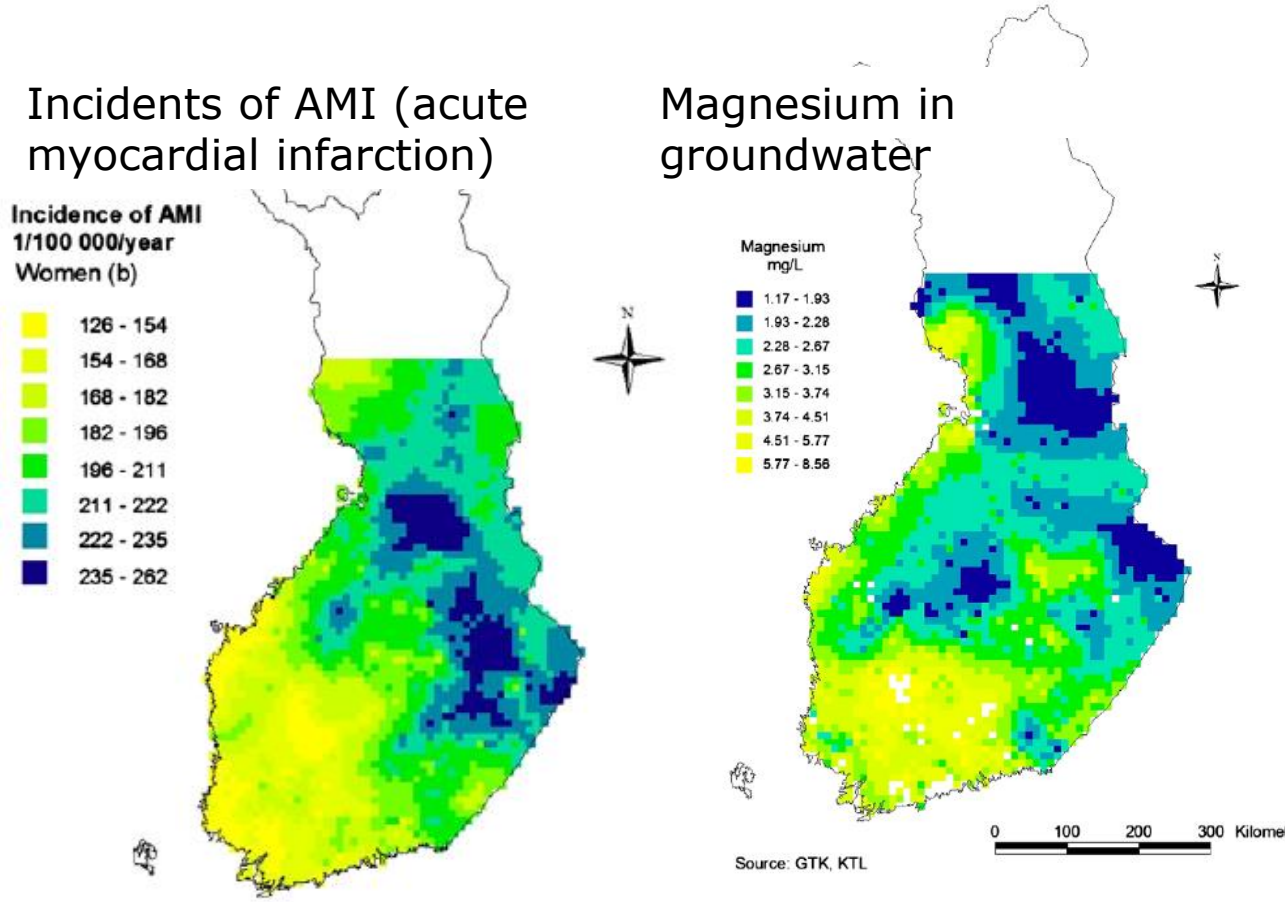
Caries relationship from Bruvo et al (2008)

Sundhedseffekter eksempel 2

- Morris et al 2008 found: *Hard drinking water does not protect against cardiovascular disease…*
- However, Kousa et al. 2008 found relationship:

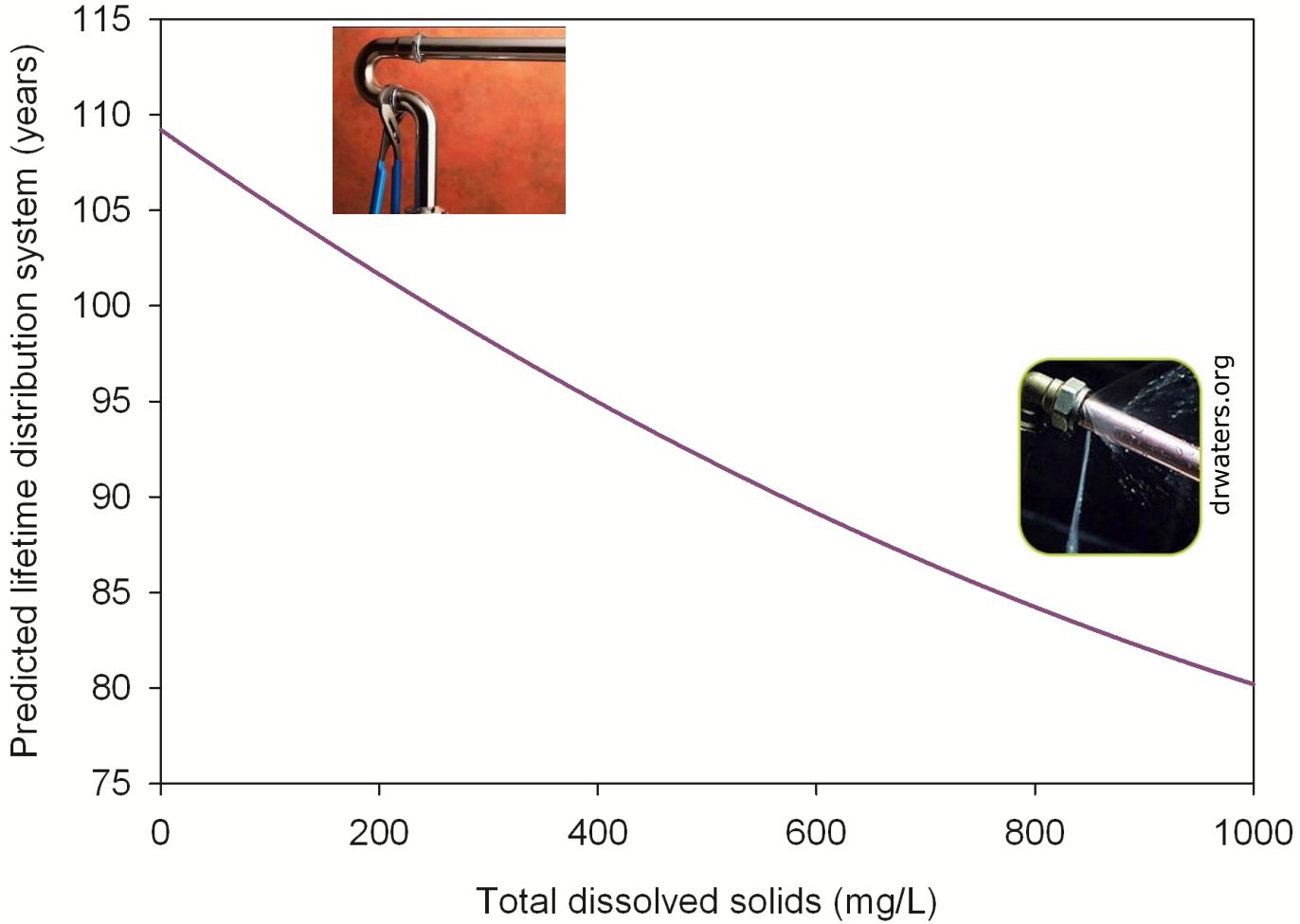
Incidents of AMI (acute myocardial infarction)

Magnesium in groundwater



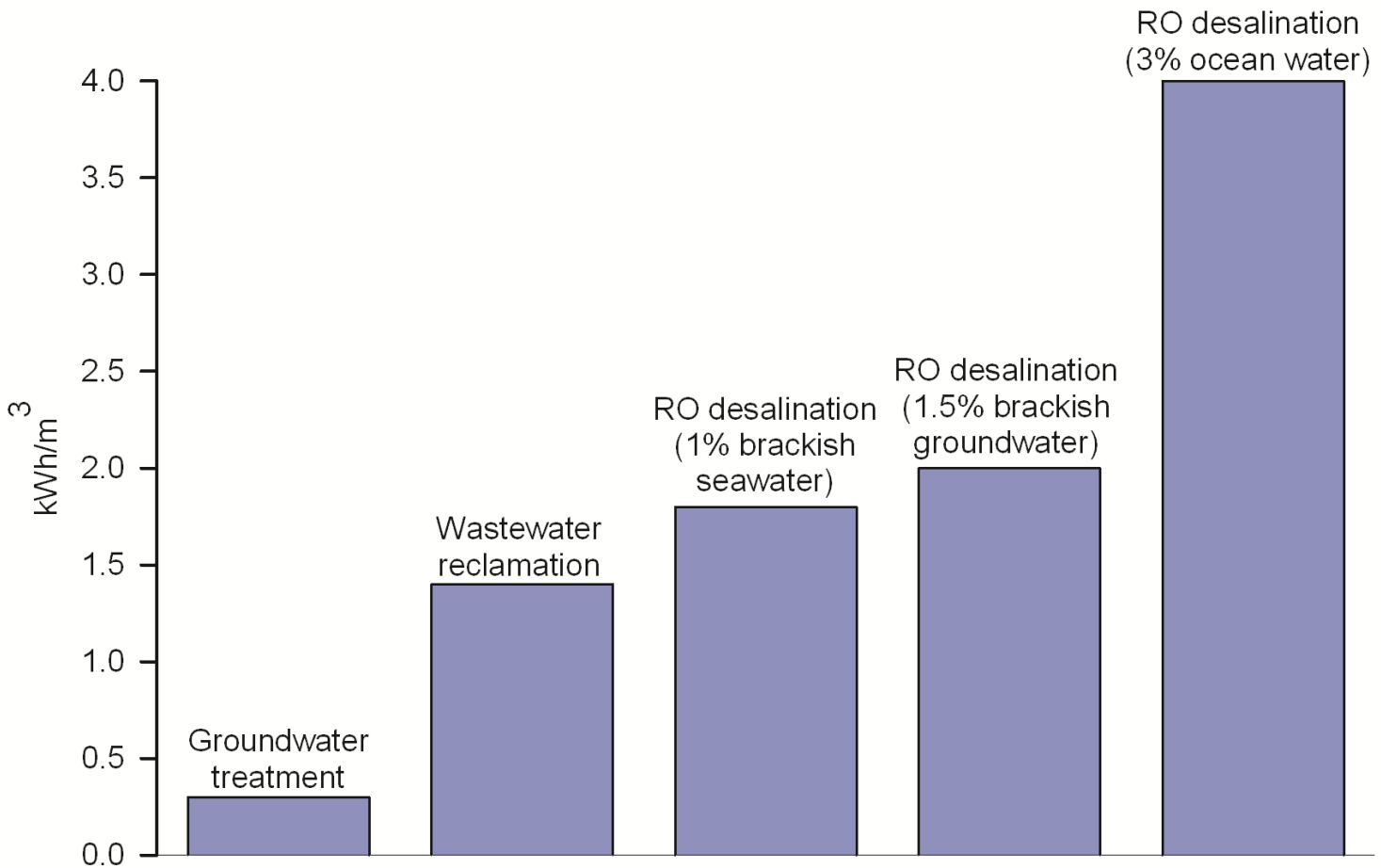
Picture from Kousa et al. *Magnesium in well water and the spatial variation of acute myocardial infarction incidence in rural Finland* (2008)

Levetids eksempel



Relationship from Characklis (2004)

Energiforbrug



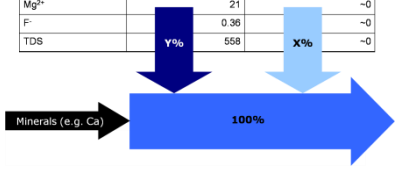
(Modified from Rygaard et al 2010)

Metode - Systemanalyse

Beregn vandkvalitet → Estimer fysiske effekter → Estimer omkostninger af ændret vandkvalitet

Implication: Finding the optimum water composition

Parameter (mg/l)	Typical Danish groundwater	Desalinated water from the Baltic Sea
Hardness (as $CaCO_3$)	373	~0
Ca^{2+}	115	~0
Mg^{2+}	21	~0
F^-	0.36	~0
TDS	558	~0



€2600/yr

Estimer omkostninger ved behandling mm

Sammenlign vandforsynings-alternativer

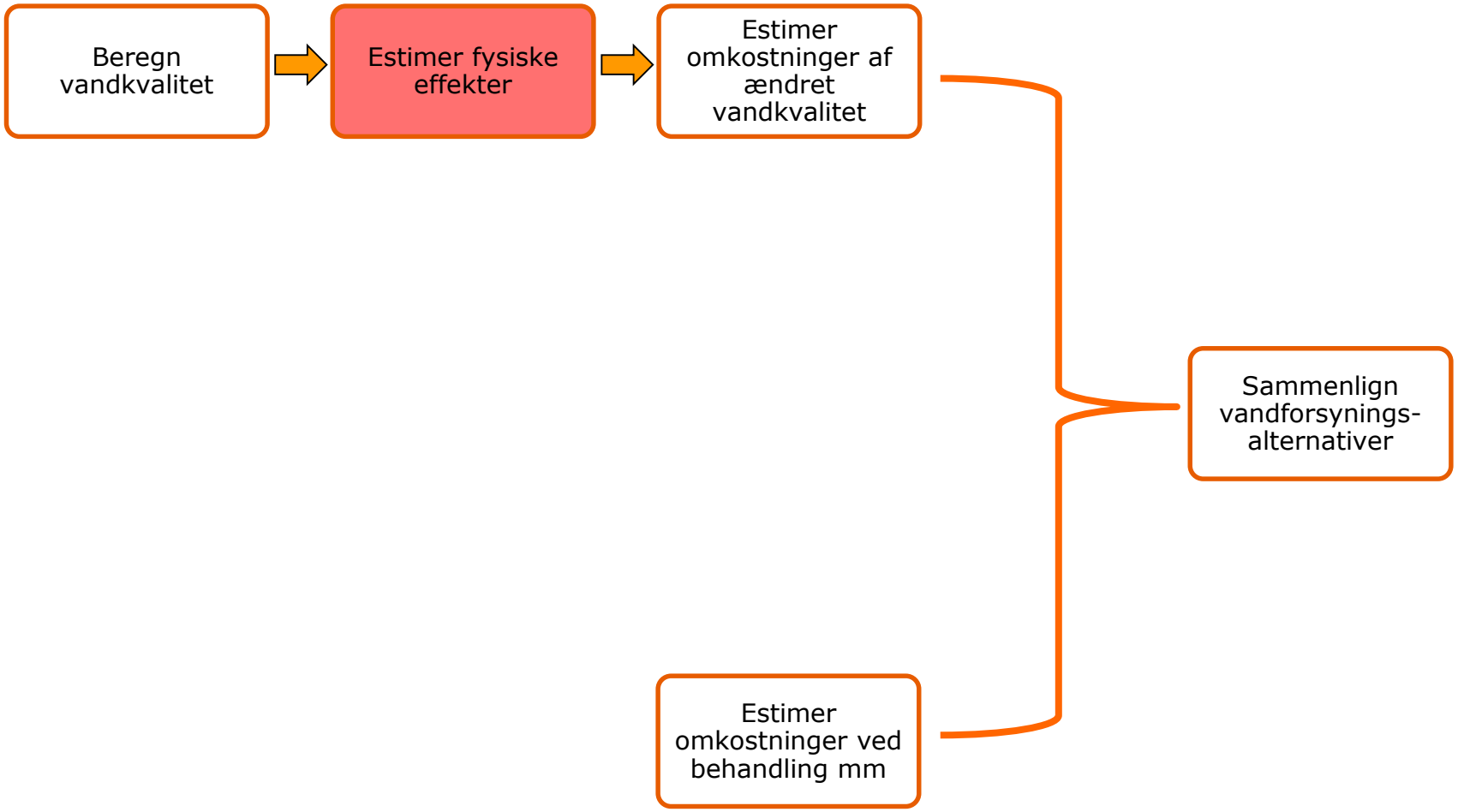
Nuværende system:

€0.35/m^3

Nyt system:

€??/m^3

Metode - Systemanalyse

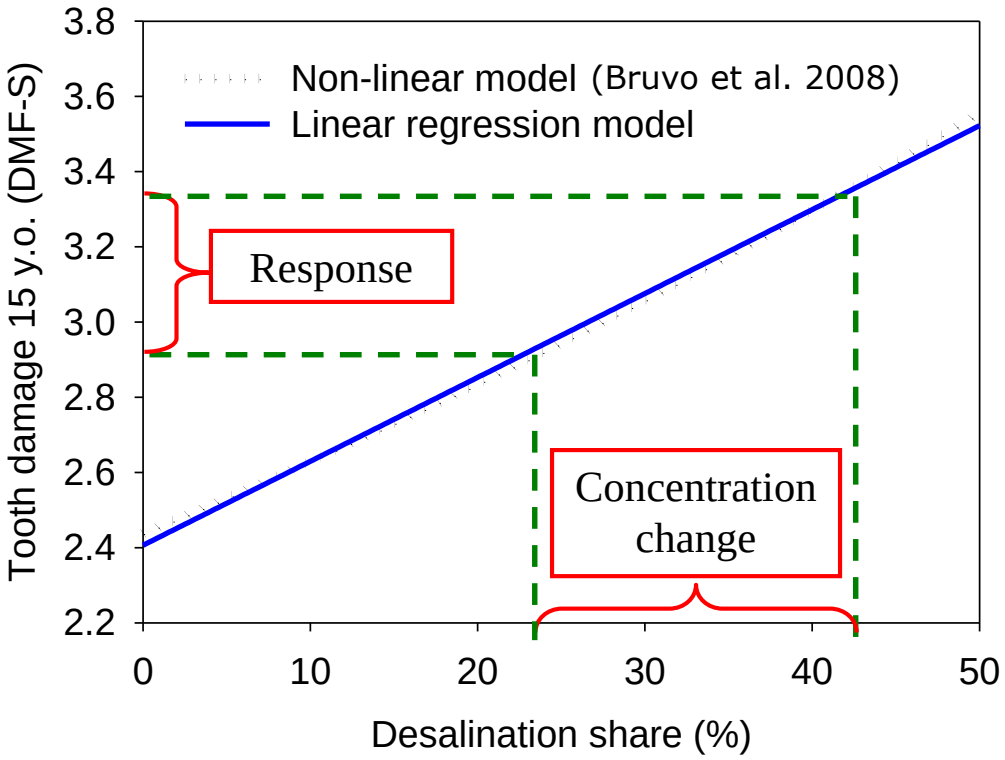


Bestmme fysiske effekter

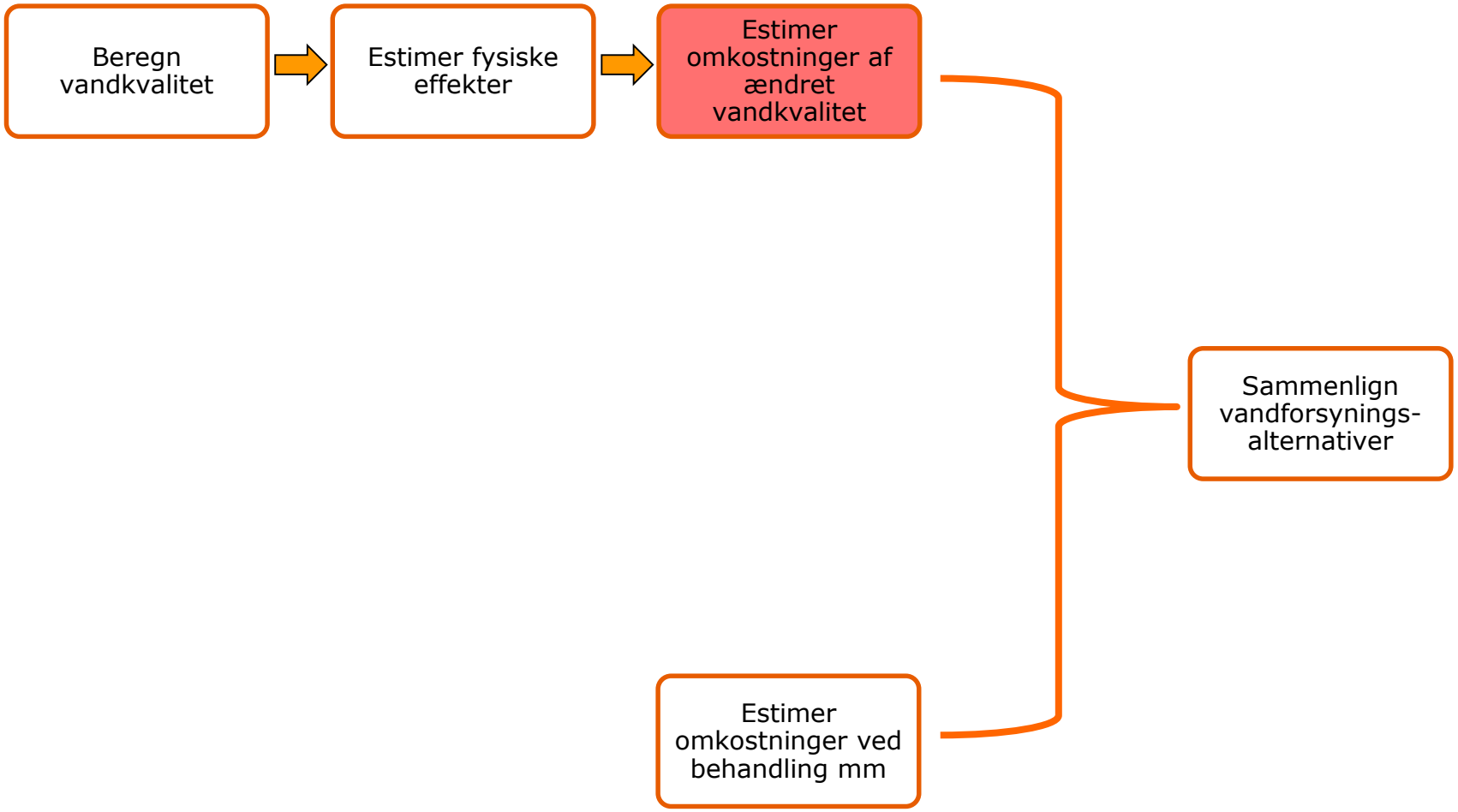
- Baseret på litteraturstudier
- Etablering af dosis-respons relationer:

$$R_i = s_i \cdot dc_i \cdot P_i$$

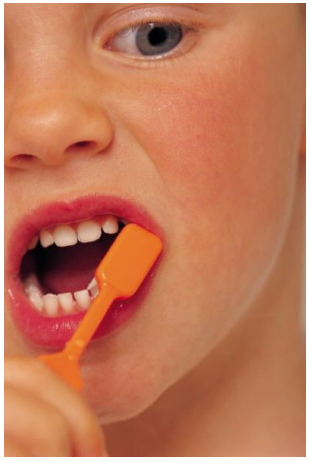
  - R = response,
  - s = slope,
  - dc = change in mineral content,
  - P = scaling factor (e.g. number of persons affected), and
  - i impact category



Metode - Systemanalyse



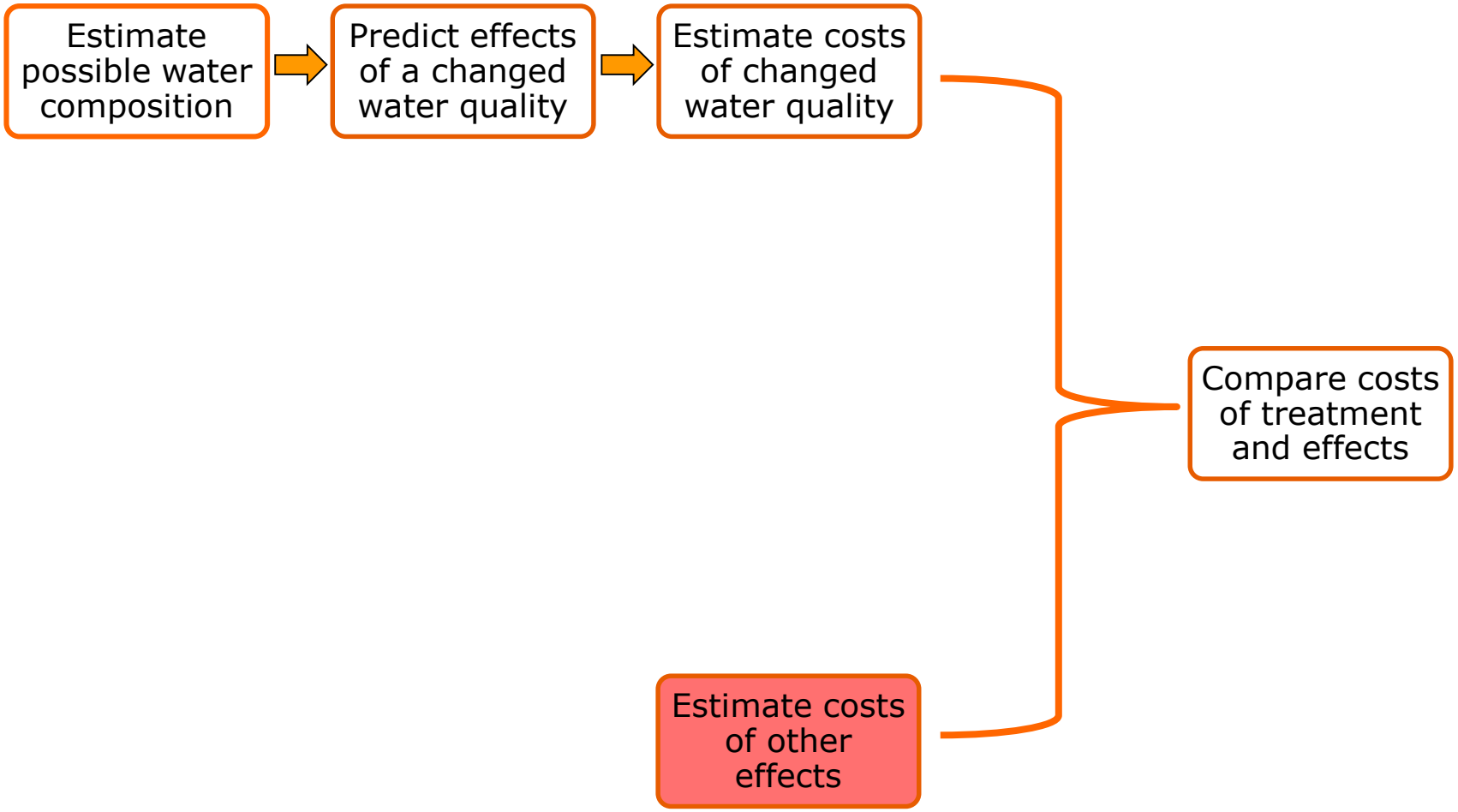
Eksempel på estimaeret effekt: 10% afsaltet vand i København



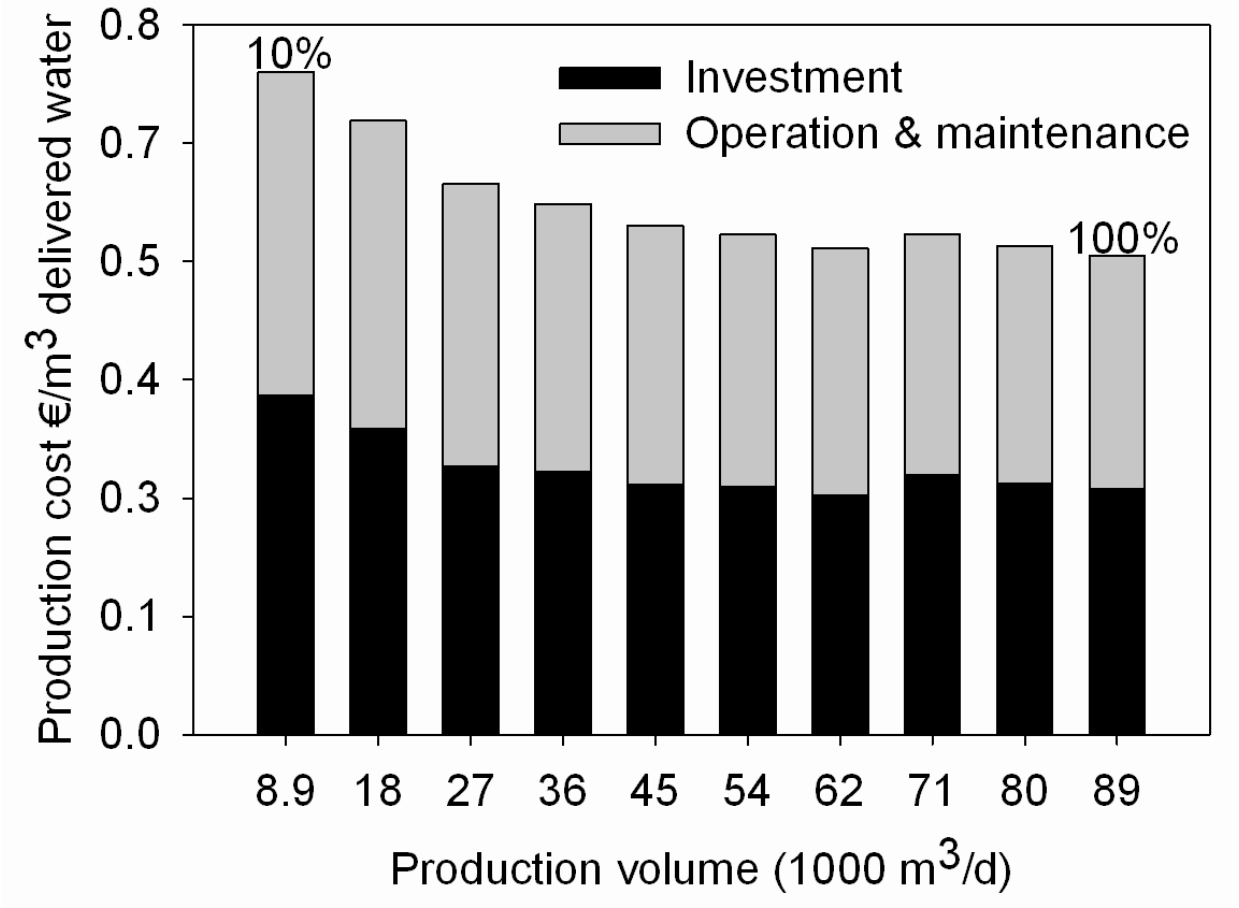
Calcium: 117 → 110 mg/l, Fluoride 0.48 → 0.43 mg/l

Year 2009	Baseline	Change		Scaling factor	Cost	Economic impact	
	DMF-S	%	DMF-S	Persons	€/case/yr	million €/yr	€/m^3
Dental caries	3.0/person	+7%	+0.2	500,150	6.7	-0.6	-0.02

Method - System analysis



Omkostningen til afsaltning



10 – 100% af Københavns vandforbrug

(DKK 4-5.5/m^3)

Omkostningen ved alternativ vandforsyning

Re-etablering af vandføring i Mølleåen

	Rørføring	**Opgradering af spildevandsanlæg**
Investment	35.5 mill.	50 mill.
Amortized cost per year (3%, 30 yr)	1.8 mill.	2.6 mill.
Operation & Maintenance per year	0.6 mill.	*3.2 mill.
Sum		Total 8.2 mill. dkr/yr (1.3 dkr/m^3)

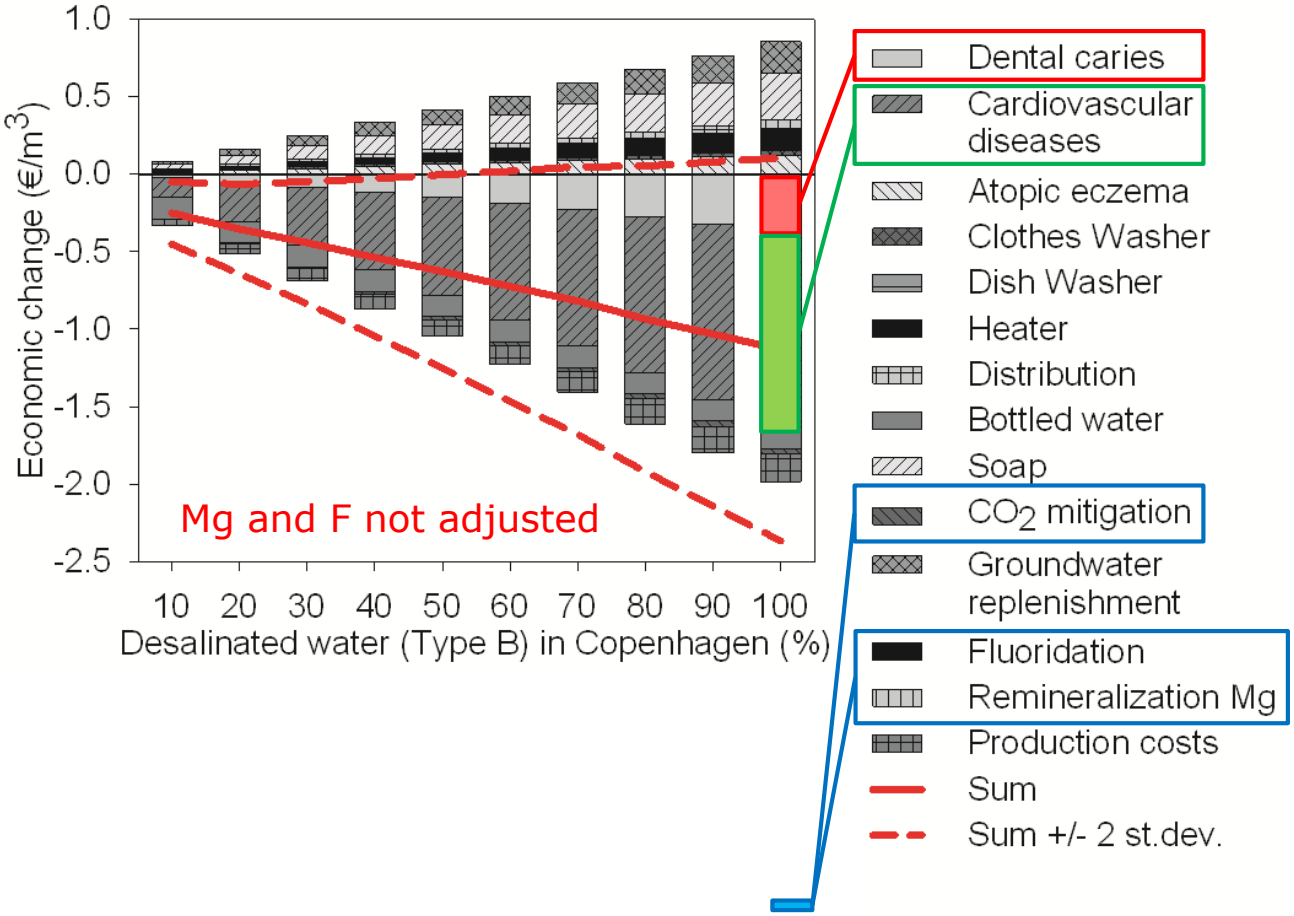
*Guesstimate 0.5 dkr/m^3.

Omkostningen af en øget CO_2-udledning

€/ton CO_2-eq				
Quotas EUA *European Union Allowances 2008-'09*			*IPCC* *expected mitigation costs (2007)*	
Average	Min	Max	25% reduction in 2030	45% reduction in 2030
18 €/ton	8 €/ton	29 €/ton	15 €/ton	74 €/ton

Source: Bluenext.eu and Sims et al 2007

Økonomiske effekter i København



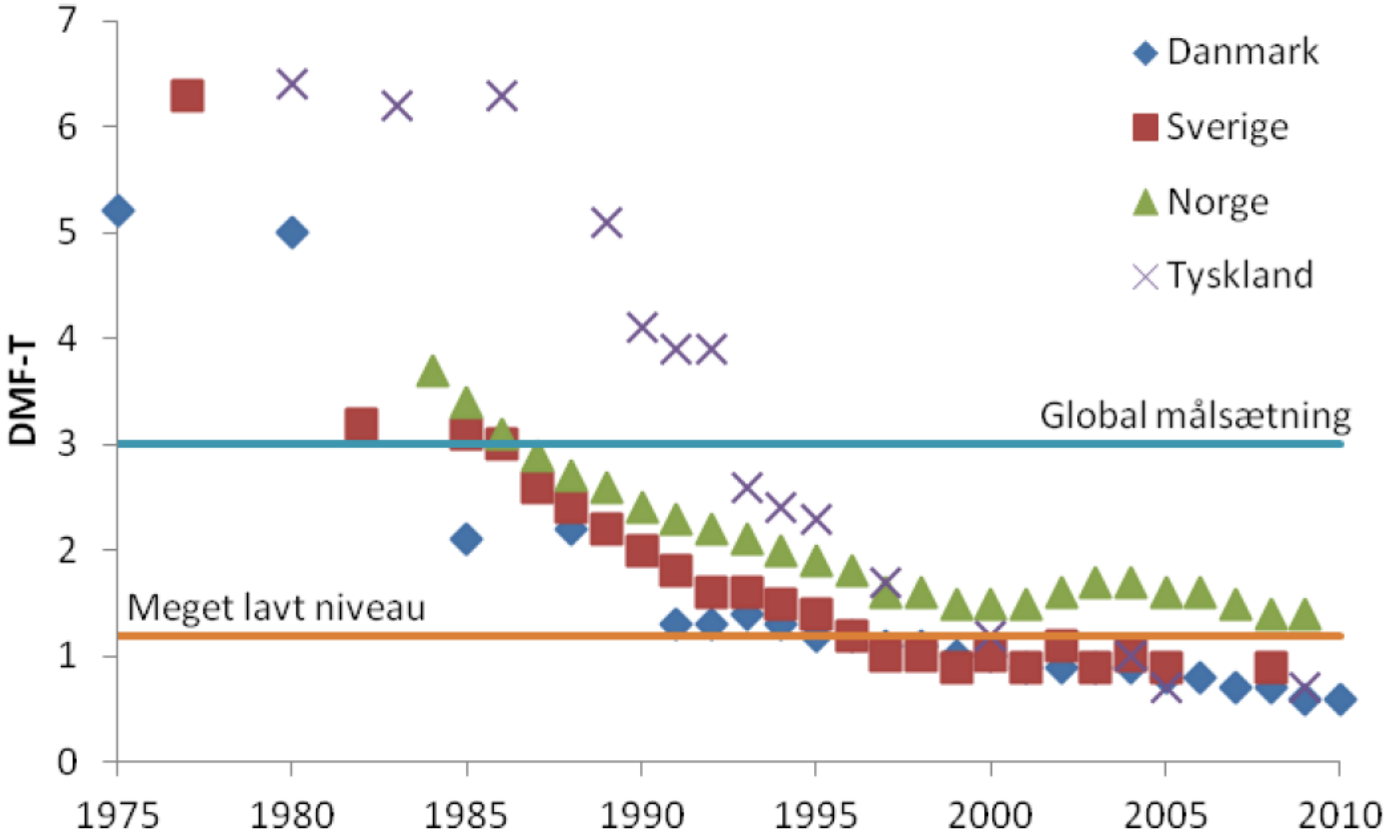
Remineralized with Mg and F

Begrænsninger

- Forsigtig opgørelse af omkostninger – reelle omkostninger vil være større:
  - Tab af arbejdsduelighed, livskvalitet:
  - Brudrater i rørsystemer og tab af indbo
  - Etc.

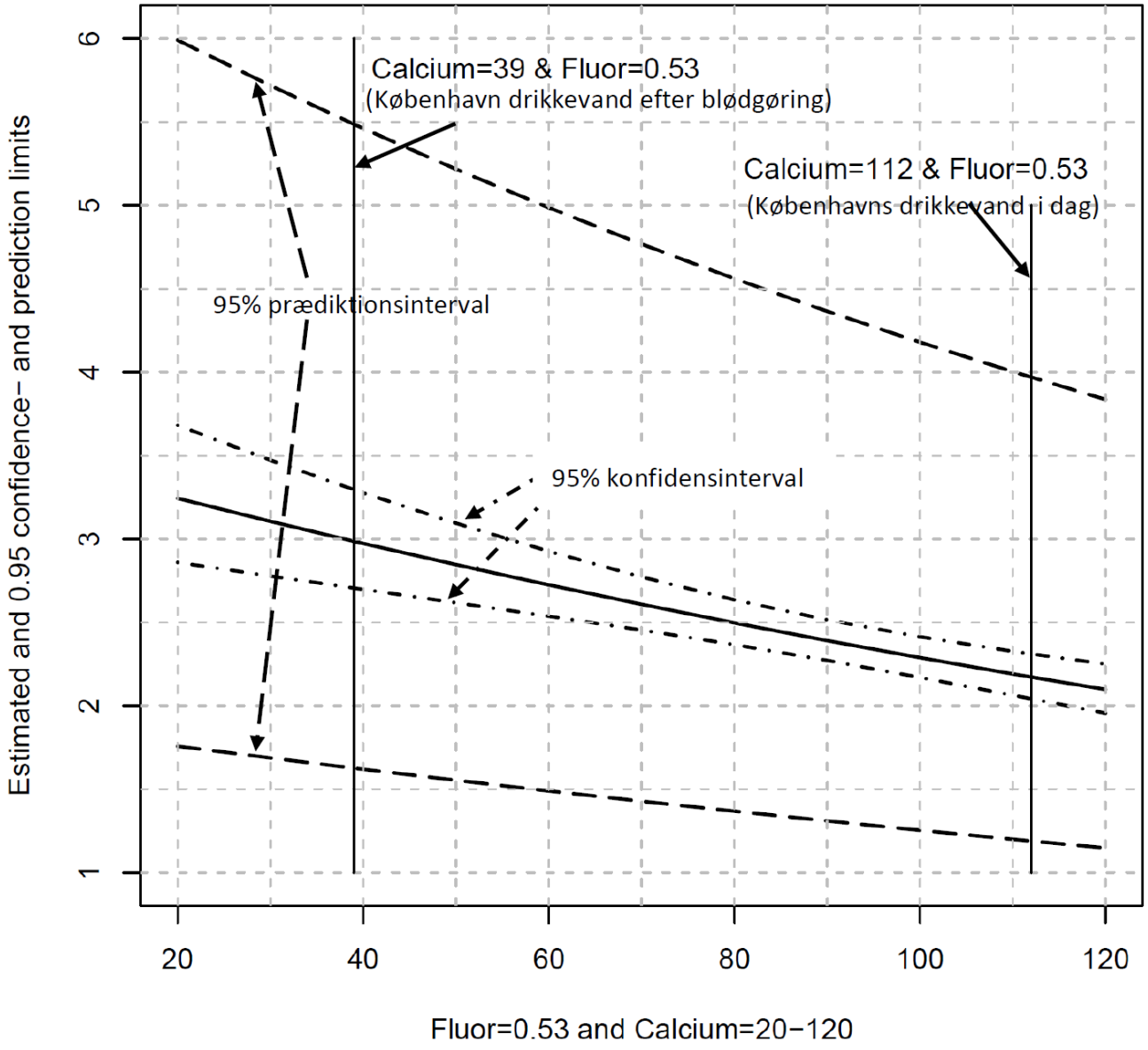
Photo by Luke Roberts

Eksempel på usikkerhed: Udviklingen caries 1975-2010



Figur 1. Udvikling i forekomsten af caries blandt 12-årige i Danmark og nabolande i perioden 1975-2010. WHO's officielle målsætning er DMFT<3 og WHO betegner DMFT<1,2 som meget lavt niveau (Petersen, 2003). **DMFS-værdier kan antages at være 1,5 gange de rapporterede DMFT-værdier**

Forudsigelse af sundhedseffekter



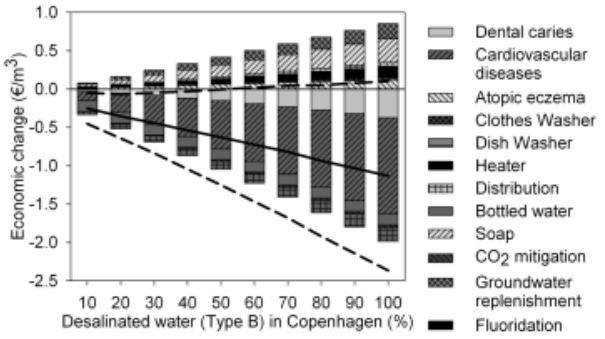
Figur 3. Estimeret DMFS niveau 2004 baseret på publiceret relation mellem calcium, fluorid i drikkevandet og DMFS niveau blandt 15-årige I Danmark (Bruvo et al., 2008)**. Figuren er udarbejdet af Henrik Spliid, professor, ISCC, DTU Dataanalyse.**

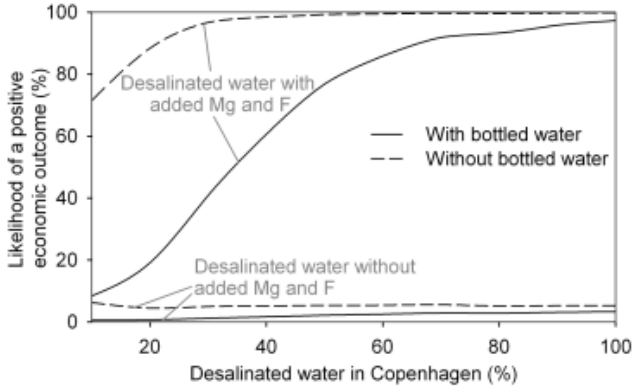
Et bud på optimal drikkevandsvandkvalitet

Parameter (mg/l)	Danish Ministry of the Environment (2007)	Australian Government (2004)	World Health Organization (2004)	Lahav & Birnhack (2007)	New proposal Rygaard et al. (2011)
Mg	-	-	-	-	>10
Ca	<200	-	-	32-48	40-50
Hardness (as $CaCO_3$)	89-534	<200	-	-	<150
F	<1.5	<1.5	<1.5	-	0.5-1
TDS	<1500	<500	-	-	<200

De væsentligste resultater af studierne

1. Metode til opgørelse af de direkte omkostninger ved en ændret vandkvalitet – påvirkningerne er sammenlignelige med, eller større end produktionsomkostninger
2. Nyt bud på optimal drikkevandsvandkvalitet
3. Ikke vist: Metode til beregning af usikkerheden på de estimerede fysiske effekter





Parameter (mg/l)	Proposal Rygaard et al., (2010)	Fulfilled by
Mg	>10	
Ca	40-50	
Hardness (dH)	<8 dH	(11/4%)
F	0,5-1	(15/6%)
Total dissolved solids	<200	(3/1%)

Rygaard et al. 2012 *Redegørelse om sundhedseffekter af blødgøring i København specielt med fokus på caries.* DTU Miljø.

Rygaard, M. et al 2012: *Designing water supplies: Optimizing drinking water composition for maximum economic benefit.* Water Research

Implication: Finding the optimum water composition

Parameter (mg/l)	**Typical Danish groundwater**	**Desalinated water from the Baltic Sea**
Hardness (as $CaCO_3$)	373	~0
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